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## WIDEBAND ANTENNA AND RECEIVER CALIBRATION

The present invention relates to antenna calibration and more particularly, but not exclusively, to a method of calibrating a wideband antenna and receiver system. The method of calibration is particularly, though not exclusively, suitable for use with phased array antennae, particularly of the type found in mobile cellular telephone systems used for the reception of wideband signals and employing digital receivers and digital signal processing techniques.

Mobile cellular telephone systems usually comprise a network of base stations operable to communicate with mobile handsets of users (subscribers) in order to provide telephone and other services.

The operational range of base stations in mobile telephone systems is typically of the order of 10 – 20 kilometres (km).

Typically, the power of signals transmitted by base stations is of the order of a few tens or even hundreds of Watts. The frequency of the signals is usually in the low microwave region of the electromagnetic spectrum, typically around the 1 – 2 GHz range. This range of frequencies is found in Global System for Mobile (GSM) cellular mobile telephone networks in particular. Mobile communications systems operating according to other mobile communications standards, whether cellular or otherwise, have corresponding operational frequency ranges. Examples of other mobile communication systems include digital audio broadcasting (DAB) systems, coded division multiple access (CDMA), Quadrature Phase Shift Keying (QPSK) communication systems, High Performance Radio Local Area Networks (HIPERLAN) and Universal Mobile Telecommunication Systems (UMTS) telephone networks.

Signals generated in such systems occupy a wide bandwidth and are often modulated with pseudo-random codes or sequences that have a good auto correlation function. Correlation techniques are widely used in GSM and similar communications systems to perform signal synchronisation, detection and other signal processing tasks.

Phased array antennae comprise a plurality of antenna elements arranged in an array. Each individual antenna element in the array has an associated feed cable and associated receiver components. By processing and combining the signals received from each of the elements in the array it is  
5 possible to control the characteristics of the overall synthetic beam pattern (e.g. beam shape, pointing direction, nulling of interference), for example by applying different amplitude weightings, different phase shifts and time delays to signals received from each of the antenna elements before combining them. Amplitude weightings, phase shifts or time delays may be applied to received signals in  
10 the analogue or digital domain, as is well known.

Increasingly, phased array antennae are being employed in cellular telephone networks, for purposes such as maximising traffic capacity using spot beams, interference reduction and the locating mobile handsets. For example, International Patent Application number WO-A-9526116 (Ericsson GE Mobile  
15 Inc) describes a phased array cellular base station that makes use of a number of individual phased array antennae, each arranged to transmit a different individual radio channel of a different frequency at any one time. The power radiated by each phased antenna array is selectively controllable to reduce possible interference while maintaining communications with respective  
20 mobile units both near and far from the base station.

Another example of a cellular base station that employs a phased array antenna is described in United States Patent US-A-2001027103 (Harris Corporation). In the system of US-A-2001027103, each base station employs a phased array antenna to enable the base station to define its antenna coverage pattern with respect to any mobile transceiver so as to minimise interference  
25 from one or more other transceivers, so enabling a reduction in frequency reuse distance.

In practice, there are minor differences in the characteristics of each of the cables, components and individual antennae elements in a phased array antenna so that it is necessary, or at least desirable, to calibrate the phased array antenna and associated receiver system so that optimal performance can  
30 be achieved and maintained. It is known to calibrate phased array antennae,

and associated receivers, by injecting a sinusoidal (sine) wave signal into each of the antenna element feeds and subsequently measuring the phase and amplitude variations through each corresponding receiver channel. It has been found however that such a technique is not optimal when used in certain types 5 of phased array antenna and receiver system and particularly those which operate using digital receiver techniques and which are required to receive wideband signals.

### Summary of the Invention

- 10 According to a first aspect of the present invention there is provided a method of calibrating an antenna and receiver system having multiple channels, each channel comprising an antenna, feed cable and associated receiver components, the method comprising the steps of:
  - (i) applying a wideband calibration signal to each antenna feed, the 15 wideband calibration signal having similar characteristics to an operational signal;
  - (ii) measuring a correlation response across a plurality of said channels;
  - (iii) deriving an estimate of signal transfer response for each of said plurality of channels based on the correlation response; and
- 20 (iv) applying compensation factors for each of said plurality of channels derived from the estimate of signal transfer response.

In order to optimise performance and increase flexibility, preferred embodiments of the present invention are adapted for use with a phased array antenna- system incorporating digital receivers for synthetic beam/null 25 generation and steering. Such arrays comprise a number of antenna elements, with parallel receiver channels comprising cabling, analogue-to digital converters (ADCs) and digital signal processing systems. In normal operation, the outputs of these channels are suitably combined in delay, amplitude and phase to create the desired synthetic antenna beam patterns. This process can

only be performed successfully if the signal transfer characteristics of each of the channels are known.

In a preferred embodiment of the present invention, said plurality of channels comprise all said multiple channels and, at step (ii), the correlation response is measured with reference to said wideband calibration signal. Alternatively, said plurality of channels comprise all but a selected one of said multiple channels and wherein, at step (ii), the correlation response is measured with reference to said selected one channel.

Preferably, the wideband calibration signal comprises a pseudo-random binary sequence modulated according to a modulation scheme providing similar modulation characteristics to those of the operational signal.

If a phased array antenna and receiver system which is adapted for use with wideband signals is calibrated using a mono-frequency sine wave, as with known calibration arrangements, then the resultant calibration factors which are obtained may only be applicable to a narrow frequency band around the frequency of the sine wave and not to the full bandwidth of the operational signal, as is possible through use of the present invention, because the receiver system may exhibit different characteristics outside this narrow frequency band.

Furthermore with a digital receiver system, differential delays between channels may be introduced due to effects such as ADC clock phasing and skew, latency of data stream processing, storage and buffering activities and interface protocols etc. Preferred embodiments of the present invention are particularly well suited to taking account of such effects when used to calibrate antenna systems employing digital receiver techniques.

In a preferred embodiment of the present invention, either a pseudo-random binary sequence, or a symbol sequence with the characteristics of a typical GSM signal is readily and easily generated by test equipment. Both types of signal possess good auto-correlation properties. GMSK modulation is then preferably applied and the result is up-converted to an operational receiver frequency to provide the calibration signal.

After processing through the antenna feed and receiver system the calibration signal in each channel is cross-correlated with the original calibration signal, or with the output of one of the receiver channels, to obtain the delay, amplitude and phase characteristics of each receiver channel.

5 Preferred embodiments of the present invention will now be described by way of example only, and with reference to the accompanying drawings, of which:

Figure 1 is a diagram showing a phased antenna array calibration arrangement according to a first embodiment of the present invention; and

10 Figure 2 is a diagram showing a phased antenna array calibration arrangement according to a second embodiment of the present invention.

#### Detailed description of Preferred Embodiments of the Invention

15 An arrangement for calibrating a phased antenna array and receiver system will now be described with reference to Figure 1, according to a first preferred embodiment of the present invention.

Referring to the Figure 1, a portion of a phased antenna array and receiver system is shown, with four receiver channels illustrated, in which each of the antenna elements in the array of antenna elements 10 are linked by 20 means of switches 12, 13, 14, 15 and respective antenna feeds 17, 18, 19 and 20 to digital receivers 22, 23, 24 and 25 respectively. When the switches 12-15 are set to a first position, signals received at the antenna elements 10 are routed to the digital receivers 22-25 in the normal way. However, when the switches 12-15 are set to a second position – a calibration mode - a calibration 25 signal generated by a signal generator 35 is input to each of the antenna feeds 17-20 and hence to the digital receivers 22-25. An output from each of the digital receivers 22-25 is connected a respective complex (I, Q) correlator 27, 28, 29 and 30. The calibration signal generated by the signal generator 35 is also input directly to each of the complex correlators 27-30 so that they can 30 each perform a complex correlation of the calibration signal received over their

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respective antenna channel with the directly supplied calibration signal. Example outputs of the correlators 27-30 for this first preferred embodiment are shown (32) in Figure 1.

As mentioned above, known calibration methods for use in phased array  
5 antennae make use of a sine wave calibration signal or other narrow band  
signal when attempting to measure a signal transfer response for each of the  
channels of an antenna array. Conventional methods of calibration thus take  
little account of the broadband signal reception characteristics of the antenna  
and receiver components and do not allow delays due to latency or analogue to  
10 digital converter clock skew which may be present in digital receiver systems, to  
be measured.

In this first preferred embodiment, the signal generator 35 is arranged to  
generate a calibration signal having characteristics of a typical GSM signal.  
However, the signal generator 35 may be arranged to generate calibration  
15 signals typical of the particular mobile communications systems in which the  
phase array antenna is deployed, if other than a GSM system. In particular, the  
signal generator 35 operates by applying GMSK modulation to a preselected  
pseudo-random binary sequence having good auto-correlation properties, and  
up-converting the modulated signal to the required channel calibration  
20 frequency to produce the required calibration signal.

In this first preferred embodiment, each of the complex correlators 27-30  
perform a complex correlation of the calibration signals received over the  
respective receiver channel with the calibration signal supplied directly from the  
signal generator 35. The outputs from each correlator 27-30 are analysed in a  
25 calibration processor (not shown in Figure 1) in order to determine the transfer  
characteristics of each channel, advantageously based upon bandwidth and  
modulation characteristics similar to those encountered in normal operation of  
the antenna and receiver system. In particular, the calibration processor is  
arranged to search across an appropriate range of signal delays for each  
30 receiver channel to find the position of peak response in each correlator output,  
which identifies the channel delay. As a consequence of the low sidelobes  
typically associated with the autocorrelation functions of the signal types of

interest in GSM systems for example, the position of the correlation peak corresponding to the channel delay is easy to identify. The calibration process operates in the complex signal domain and hence "In Phase" (I) and "Quadrature" (Q) output values are produced. For the peak response delay the 5 calibration process may derive the amplitude response for the respective channel using the value of  $(I^2 + Q^2)^{1/2}$ . Furthermore the channel phase shift  $\varphi$  is derived from  $\tan^{-1} (-Q/I)$ . Therefore only three measurements per channel (delay, amplitude and phase) need to be made by the calibration processor in order to obtain an appropriate set of compensation parameters to enable the 10 antenna feed and receiver system to be calibrated.

The calibration process may be repeated as required so as to compensate for drifts or errors that may be introduced, for example due to changes in ambient conditions or changes in clock signal phasing after each system power up.

15 Thus it can be seen that invention also overcomes problems often associated particularly with digital systems, namely differential delays caused by factors such as analogue to digital conversion clock phasing and skew, data stream processing, buffering and storage.

Referring to Figure 2, in a second preferred embodiment of the present 20 invention, rather than supply the calibration signal directly to the complex correlators 27-30, it may be simpler in practice to use the output of one of the receiver channels as the calibration signal source for cross correlation purposes. This alternative embodiment, which exploits the same principles as the first embodiment, may be adequate for many applications and may be 25 simpler to implement. In this alternative embodiment the calibration processor (not shown in Figure 2) measures the amplitude, phase shift and delay of each antenna receiver channel relative to the channel selected as the calibration signal source.

There are a number of advantages shared by preferred embodiments of 30 the present invention over known antenna and receiver system calibration arrangements.

Firstly, since the correlation can be performed over a wide symbol span, there is obtained considerable processing gain against noise, thus enhancing the accuracy of the calibration. Secondly the calibration signal has the same or similar spectral and modulation characteristics as a normal GSM signal, so that

5 the effects of filter responses, amplifier group delays etc. will be accurately reproduced in the calibration. Thirdly, the amplitude and phase characteristics of each channel are simply obtained from the real and imaginary results of complex correlations. Fourthly, the position of the easily identified correlation peak permits the delay through each channel to be measured. This may be

10 important when digital receiver techniques are employed, since the latency through digital systems may be significant and may in addition be different at each power up. This can occur, for example, if the DSP or interface clocks are derived from dividing down a high frequency master clock, so that each logic block in the system then has the choice of selecting at random from one of a

15 number of possible clock phases at power up.

It will be appreciated that the invention has been described by way of example only and that variation to the above described embodiments may be made without departing form the scope of the invention.